International Journal of
Emerging Research in Management &Technology
ISSN: 2278-9359 (Volume-6, Issue-8)

Research Article | **August 2017**

Environmental Impacts of the Red Ceramics Industry in Northeast Brazil

Raphael Abrahao, Monica Carvalho*
Department of Renewable Energy Engineering, Federal University of Paraíba,
Brazil

Abstract—

This paper exposes the current negative environmental impacts that have been identified in various stages of ceramic production in Northeast Brazil, through the extraction of clay, the generation of solid residues, the extraction of native vegetation for burning, and emissions into the atmosphere. A representative factory was studied, located in the municipality of Guarabira (Northeast Brazil). Although the area is developing economically, some stages of the process are not being accomplished in a way that ensures the sustainability of the activity in the environment. The pressing need for an optimized and environment-friendly ceramic production has triggered research on the production process and alternative methods. The environmental impacts observed were described herein, and a Life Cycle Assessment was carried out to quantify the carbon footprint associated with the productive process of the factory.

Keywords— carbon footprint, environmental assessment, LCA, red ceramics, energy.

I. INTRODUCTION

Red ceramic materials are mainly composed of clay, a material that usually contains iron in the form of iron oxide, which gives the ceramic its red hue [1]. Clay is the main component in the production of structural elements at construction sites, e.g., bricks and tiles. The distribution of ceramic industries is highly dependent on the occurrence of clay deposits, with industries usually located within 250 km of the clay deposit.

The ceramic industry is an important economic activity in Brazil, with production often still rudimentary and detrimental to the environment. Despite the great variety of products that can be made from red ceramics, the production stages are basically the same throughout Brazil: clay seasoning, mixture preparation, molding, drying, and thermal processing (sintering/burning) in the kiln.

Red ceramics industries are distributed throughout Brazil and are mostly family-owned or small industries. This paper exposes primarily a Northeast-Brazilian point of view. According to the Brazilian National Association of Ceramics Industry [2], there are approximately 6,900 ceramic industries in Brazil, which generate 293 thousand direct jobs, 900 thousand indirect jobs, and an annual income close to US$ 9 billion (R$18 billion). However, although economically prosperous, this activity causes impacts to the environment throughout its production stages – from raw materials extraction, materials production, transportation, construction, use, maintenance and demolition [3, 4]. Going a step further than the observation of environmental impacts, the Life Cycle Assessment methodology enables the quantification of the potential environmental impacts associated with a product, process or activity [5, 6].

The objective of this study was to expose the current negative environmental impacts that have been identified in various stages of ceramic production in Northeast Brazil, and develop a Life Cycle Assessment to quantify the carbon footprint associated with the productive process of a representative factory.

II. MATERIALS AND METHODS

A. Study case

The Guarabira area (Paraíba, Northeast Brazil) was exhaustively and systematically analyzed to estimate the dimension and characteristics of the environmental problems caused by a high concentration of red ceramic industries. This area of Northeast Brazil was chosen because it is a well-known region that concentrates ceramic industries. The Guarabira area has soil with a high concentration of clay (with high purity levels) as well as favorable physical/climate conditions/characteristics for the production of ceramic, which attracted a large number of industries and made the area economically important for the rural and coast areas of Paraíba.

The Cerâmica Santa Cecília Ltda. was considered representative of the industrial profile in the Guarabira area. Detailed research was carried out on all industrial processes carried out by the company as well as their related environmental impacts. The industry's reforestation project was also analyzed. Thermodynamics analyses were carried out in Carvalho & Silva [7].

The city of Guarabira (Figure 1) is located on the Borborema Plateau at latitude 6º51'17" South and longitude 35º29'24" West. The district occupies an area of 146 km^2 and is 96 km away from João Pessoa, the capital of Paraiba state.

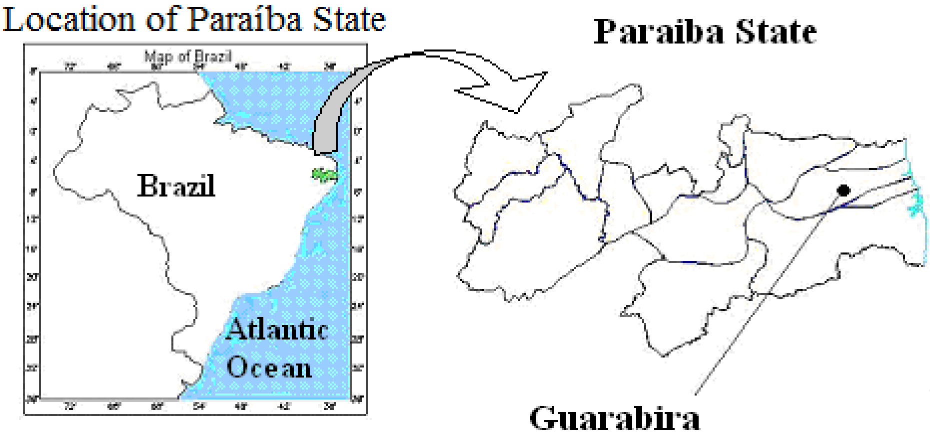

Fig. 1 Location of Guarabira in Brazil (left) and in Paraíba State (right).

B. Production process

In the investigation and planning stage, the production processes of the red ceramic industry were analyzed to better understand the techniques and pinpoint the environmental impacts in each stage of the production of red ceramics (clay extraction, generation of solid residues, extraction of native vegetation, and emission of gaseous effluents).

Once clay is extracted from natural deposits, it undergoes seasoning to stabilize and homogenize its properties. The seasoning stage is characterized by simply piling the clay and leaving it exposed to the environment. The preparation stage consists of mixing raw materials at specific proportions, depending on the desired end-product characteristics. The large lumps of clay are eliminated in a disintegrator, followed by a mixer, where water is added. When the desired plasticity is reached, the mixture is homogenized (air bubbles and residual gravel are removed), followed by a molding process. Some of the most common molding methods for ceramics include extrusion, slip casting, pressing, tape casting and injection molding. After the pieces are molded, raw ceramics contains 18-25% moisture, which must be decreased by a multi-step drying process. Initially, the pieces are allowed to air-dry, which eliminates only superficial moisture; then they are transported to drying hangars or to artificial dryers. The pieces are ready for burning when a moisture content of approximately 6% is achieved. In the burning stage, the raw "dry" pieces are placed in the kiln (at 900ºC), where the final characteristics, such as color and resistance, are obtained. Periodic visits and interviews with the owner and manager of Cerâmica Santa Cecília Ltda. were the source of data.

C. Life Cycle Assessment

Life Cycle Assessment (LCA) is a consolidated and recognized methodology for the quantification of environmental impacts associated with a product, service or activity. The leading standards for LCA are ISO 14040 [8] and ISO 14044 [9]. According to the International Organization for Standardization (ISO), the goal of LCA is to compare different environmental performances in order to be able to choose the least burdensome [10]. An LCA is divided into four steps: (1) goal and scope definition; (2) inventory analysis; (3) impact assessment; and (4) interpretation, and more details can be obtained from Guineé [5, 6].

Different available impact assessment methods utilize different environmental criteria and therefore evaluate and assess different environmental aspects [11]. However, it is not always necessary to try to cover many, or even some, of these impacts if the main interest is only one impact measure, or environmental indicator [12]. The reduction of carbon emissions is among the top objectives for corporate environmental management programs; not only is the environmental impact of greenhouse gases familiar and visible to the public, it carries a high potential for future regulation [13]. The first step taken by most organizations in responding to social pressures is to determine their carbon footprint.

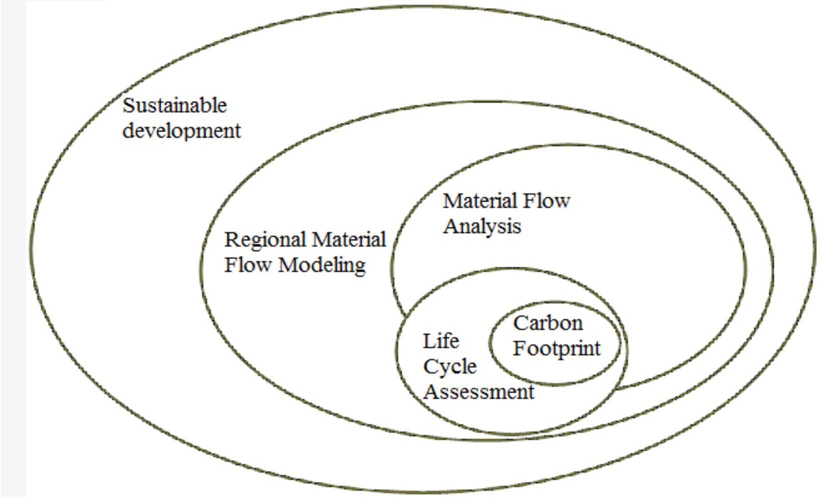

Fig. 2 Suggested concepts hierarchy (adapted from [16]).

The concept of carbon footprint is being widely used in the public debate on responsibility and mitigation against the threat of climate change. A carbon footprint (CF) is a LCA with the limited focus on one impact category only (climate change). All methodological requirements and principles of LCA apply to CF (except for comprehensiveness). ISO 14067 [14] actually contains a good share of ISO 14040/44 content [15]. Avadi [16] suggests the concept hierarchy shown in Figure 2.

CF is a term used to describe the amount of greenhouse gases (GHG) emissions caused by a particular activity or entity, and thus is a way for organizations and individuals to assess their contribution to climate change [16]. The number of calculations needed are limited as compared to a full LCA, particularly for systems where energy is the major source of greenhouse gases [17]. As CF has only one indicator – global warming potential – it is easier to communicate to stakeholders [18]. In theory, provided that the same methodology is used, this should also make it easier for consumers to compare different products based on their carbon footprint [16].

The environmental analysis carried out herein utilized software SimaPro 8.3.0.0 [19], with Ecoinvent v.3 database [20]. The environmental impact assessment method selected was IPCC 2013 GWP 100y. The Intergovernmental Panel on Climate Change (IPCC) publishes periodic reports with updated conversion factors, that are used to calculate the global warming potential index, based on the time-integrated global mean radioactive forcing of a pulse emission of 1 kg of some compound (i) relative to that of 1 kg of the reference gas CO_2 [21]. This method expresses the environmental impacts in terms of greenhouse gases, kg CO_2-eq (CF).

The functional unit, to which all material and energy flows are related to, is the production of 1 kg of brick. Table 1 shows the inventory of processes associated with the production of 1 kg of brick.

Table I Processes associated with the production of 1 kg of brick, for the study case herein considered.

Process	**Amount**
Red clay	1,3500 kg
Sand (productive process)	0,0147 kg
Lubricating oil (machinery)	1,32 x 10^{-5} kg
Polyethylene (band used to secure bricks on pallet)	8,58 x 10^{-7} kg
Transport, passenger car	0,0166 km
Clay pit infrastructure	2,00 x 10^{-10} p
Pallet (wood)	1,61 x 10^{-5} p
Tap water	0,0272 kg
Diesel (machinery)	0,0297 MJ
Electricity	0,1440 MJ
Energy (firing)	1,5200 MJ

The unit for clay pit infrastructure and pallet is p (piece), which allocates the correct amount of impacts to the final product, on the basis of its lifetime or capacity. The energy required for firing can be electricity (medium voltage), firewood (equal proportions of hard and soft firewood) or natural gas (power density: 37 MJ/m3).

III. RESULTS AND DISCUSSIONS

A. Clay extraction

In the production process of red ceramic materials, the first impact identified was related to the extraction of the raw material (clay). This is an open-pit extraction, and the mine is usually close to the industry as long distance transportation becomes financially nonviable.

In the study area, the overburden (superficial layer that lies above the clay, which is removed during surface mining) was disposed of in a vacant area. Due to this irregularity, the industry was notified by the National Department of Mineral Production and was given two alternatives: payment of a fine or development and execution of an environmental recovery project. The latter was chosen, and such project includes a chapter dedicated to the storage of overburden for future recovery of the soil (since it is not used in the ceramic process). When the overburden is replaced, there is an improvement of fertility conditions, increasing the contents of organic material and biological aspects that are crucial for the recovery of degraded areas [22]. Therefore the simple effort of piling up the overburden and storing it is an important tool for further land reclamation (the process of cleaning up a site that has sustained environmental degradation). Land reclamation can be accomplished to restore the area to its natural state (wildlife habitat) or to allow some form of human use (housing development or for recreational purposes).

Nowadays, modern society unites efforts to demand more rational extraction of natural raw materials. Clay extraction requires geophysical studies for a better application of extraction methods, water drainage, organization and distribution of the lots, and the recovery of the soil [23]. However, it has been observed that most companies in the study area extract the same material in nearby areas, making the soil useless due to the large number of holes. Usually, when one area of the clay pit becomes debilitated, another area is started without the concern of recovering the previously degraded area. The authors evaluate as extremely simple, easy and almost costless to replace the overburden in former clay pits. Extraction site reclamation should be considered as early in the planning and design stages as possible.

B. Generation of solid residues

The stage that generates the most solid residues (rejects) is the preparation and molding stage. However, those materials can be re-incorporated into the process. Figure 3 shows the losses that occur in the molding stage.

Fig. 3 Uneven cutting of the pieces (left), generating solid residues (right).

The raw residues and the dust retained by the purification systems present a similar composition to that of the initial mixture. Those materials are re-used directly in the preparation of the mixture, saving material and energy, without compromising the final quality of the product.

Solid residues are also generated after the firing stage, due to the unequal burning process that causes cracks and compromises the mechanical resistance of the product. In this case, the products are sold as lower quality materials or used in the leveling of construction sites. Figure 4 shows the fired solid residues generated.

Fig. 4 Fire solid residues (left) and disposal of residues (right).

However, it was verified that most of the solid residues are just dumped in unoccupied areas nearby (right side of Figure 3). A change in the fuel used in the kilns is suggested to address the problem of the unequal burning process. This is not an inexpensive suggestion, as a change to natural gas for example, implies in changing the way the kilns are fed, with structural changes. The option suggested by Nhlanhla, Muzenda and Zvimba [24] is that used (scrap) tires can be used as fuel, which would avoid complicated structural changes in the kilns. The main advantage is that the calorific power (MJ/kg) of scrap tires is almost three times that of firewood. However, the use of scrap tires raises the issue of toxic emissions, which can be removed by cleaning systems that capture zinc oxide, remove acidic sulfur dioxide (via lime scrubbers), and finally remove particulates left by the scrubbing process [25].

Traditional ceramic kilns (built to burn firewood or fuel oil) can be converted to burn gas (natural gas, landfill gas, biogas), with easier operation and burning, resulting in better quality products but with higher operational costs because of the high level of thermal energy losses in these types of kiln [26].

Although more expensive, better quality products are a proof of how technological improvement becomes a springboard for competitiveness and survival of ceramic companies. Concerning its advantages, natural gas does not require storage (pipes supply gas directly to the industry), provides high thermal efficiency, increases the useful life of the equipment by decreasing frequency and length of maintenance stops and the energy consumption per kg of product is 55% lower [27].

Most of the kilns in ceramic industries in Northeast Brazil are of the traditional type. The fuel conversion theme generates uncertainties among the ceramists, who are not willing to invest, claiming it is a traditional family business that should be kept that way.

C. Extraction of native vegetation

In particular, the deforestation of large areas has a devastating impact on the environment in Northeast Brazil, as reforestation programs are timidly present. According to the Brazilian Mine and Energy Ministry [28], firewood accounts for 50.1% of the energy consumed by ceramic industries in Brazil. Natural gas accounts for 28.7%, followed by electricity (7.3%), and other oil products (1.3%).

Several factors contribute to the continued use firewood in the ceramic industry, but the main factor is the price. There is a great discrepancy in cost between the commonly used energy sources in the ceramic industry sector [28]: native wood costs an average of US\$8/m^3, firewood from reforestation costs US\$23/m^3, while natural gas costs US\$442/103m^3.

The low cost of firewood explains its predominant use, especially when there are many illegal ways (viz., cheaper) of obtaining wood, which usually go unpunished (e.g. by neglecting/disregarding the tax and environmental legislations).

The pattern of using natural resources in Northeast Brazil is usually predictable. While the energy resources are still abundant, the exploration cycle repeats itself. And when one specific resource ends, another is the explored - preferably using the same conversion technology. Industries that have made great investments in oil burning systems, like Cerâmica Santa Cecília Ltda. (invested US$100,000), are now back to using firewood due to financial reasons.

Firewood is a renewable product of fundamental importance in the energy structure of the study area. Although this source of energy is already demonstrating signs of shortage, the high regeneration capacity of the mixed tropical forest contributes to the possible implantation of a program for sustainable production of firewood. For such, it is necessary to establish a program of partial cuts in periods compatible to the regeneration cycle (to make the rotation viable), to adopt appropriate techniques for the specific topology of the area, and to optimize intervals between successive cuts.

It is important to highlight that the devastation of native species in the study area is also a consequence of serious socio-political problems in the Northeast of Brazil, which forces lower socioeconomical classes to illegally extract and sell the firewood in order to survive (Figure 5). Therefore, even though environmental conservation might be a government priority, it is hard to implement conservation programs in a poverty context.

Fig. 5 Illegal extraction/transportation/selling of native species.

All the industries visited in the study area used firewood as fuel, which has led to the presence of extensive areas without any vegetation. These areas present serious erosion problems and soil loss, which impacts the development of local flora and fauna.

Brazil has, along the years, established a series of exploitation controls aimed at maintaining exploitation within sustainable levels. In 2006, the Forest Origin Document (FOD) was created to help recognize the origin of native forest products [29].

Cerâmica Santa Cecília Ltda. now uses FOD-licensed firewood, which includes a reforestation tax within its cost tax, forwarded to the Brazilian Institute of Environment and Renewable Natural Resources, proportional to the amount of wood purchased. There are no data regarding legalized firewood use by the other ceramic companies in the area.

D. Reforestation

Due to the extraction of native vegetation from the surroundings, Cerâmica Santa Cecília Ltda was responsible for assembling a technical reforestation project [30]. This project has the added benefit of avoiding a fine by the government (IBAMA Decree 3 179/99, which specifies the penalties applied to damaging behavior and/or activities regarding the environment). There is a widespread belief that reforestation can reverse some of the environmental damage wrought by clearing, for example by increasing the amount of habitat available to forest biota, facilitating the dispersal of biota between remnant forests and buffering remnants from surrounding land uses [31]. The chosen area for the reforestation belongs to the company and totalizes 2.33 hectares located at an old clay pit.

The soil in the area is at a medium state of degradation, characterized by the absence of vegetation and topsoil. The reforestation will accomplished by introducing eucalyptus (Eucalyptus globulus), sabiá (Mimosa caesalpiniaefolia) and algaroba (Prosopis Juliflora) (in equal proportions). Although eucalyptus is not native to the area, it is considered to be rehabilitating to the soil (controlling erosion and occupying areas that are inappropriate for agriculture). Algaroba is highly advisable for dry areas (such as the study area) since it has high tolerance to climate changes and to different types of soil. Sabiá is of fast growth and development, which are vital to reforestation projects (especially in Northeast Brazil). The fact that plantations of fast-growing species can help jump start the regeneration of natural species has been exploited in programs to restore natural forests in the tropics, and there are documented benefits that can be obtained from the use of colonizing species to initiate natural regeneration [32]. The success of this low-diversity planting technique depends on the ability of additional native species to reach the site from nearby intact forest, principally through seed dispersal by frugivorous birds and mammals [33].

It is important to note that the different species of trees interact differently with the soil nutrients, the water, the solar energy and the climate, guaranteeing regeneration and conservation of the soil/environment. According to Lamb et al. [33], there are several ways by which reforestation might be made more attractive to landowners. One is to develop appropriate institutional, legal, and policy settings (e.g., providing secure land tenure, elimination of "perverse" incentives that favor deforestation and forest degradation, and facilitating marketing of forest goods) and to provide financial loans or inducements to make reforestation attractive.

E. Life Cycle Assessment

The composition and characteristics of gaseous emissions from the ceramic industry are influenced by the type of fuel, nature of raw materials and residues, and the operation mode of the equipment. Due to the current environmental concerns associated with the red ceramic industry, any project that attempts to reduce the release of pollutants into the environment should be seriously considered and supported.

The CF associated with the different options available for firing the clay bricks are shown in Table 2, where BAU is the reference scenario (business as usual).

Table III Carbon footprint associated with different options of energy sources for the ceramic kiln, for the study case.

Energy source for kilns	Carbon Footprint, kg CO_2-eq/kg fired brick
Electricity (medium voltage)	0,1590
Natural gas	0,1630
Firewood	0,0564 *(BAU)*

When considering the CF of the bricks produced at the study site, the use of firewood yielded the lowest CF per kg of brick produced. Electricity (medium voltage) purchased from the electric grid and natural gas presented almost the same CF. When burning firewood, its consumption represented 25% of the final overall CF. Natural gas, in turn, represents 75% of the final CF. Electricity in kilns contributed with 73% of the final CF.

Regarding the difference in the CFs obtained herein, the IPCC guidelines do not automatically consider biomass used for energy as "carbon neutral," even if the biomass is thought to be produced sustainably, because: i) in any time period there may be CO_2 emissions and removals due to the harvesting and regrowth of bioenergy crops; ii) land use changes caused by biomass production can also result in significant GHG flows; and iii) there may also be significant additional emissions which are estimated and reported in the sectors where they occur (e.g., from the processing and transportation of the biomass, direct methane and nitrous oxide emissions from the biomass combustion, and from the production and use of fertilizers and liming if either is used in cultivation of the biomass) [34].

The advantages of using natural gas are the possibility of obtaining Environmental Certification (ISO 14000, which may become the primary requirement for doing business in many regions or industries), better final product quality and less possibility of faulty products.

From an environmental point of view, which herein mainly considered the emissions of greenhouse gases, the current practice of the study case actually presents the best environmental performance. An ornamental earthenware ceramic piece was evaluated in the context of greenhouse gas emissions, with a CF = 1.22 kg CO_2-eq/piece (cubic vessel, mass = 0.417 kg, dimensions 10 cm× 10 cm× 10 cm) [35]. The production of the ceramic piece consumed 85% of natural gas and 15% of electricity. However, other studies reported lower contributions of natural gas: in Italy, a flooring ceramic tile factory consumed 69% of natural gas and 31% of electricity [36], while the manufacturing process of ceramic gres porcellanato consumed 50% natural gas [37]. In Spain, the energy consumed during the manufacturing process of ceramic tiles was 78% natural gas and 22% electricity [38]. In Portugal, a brick factory reported that natural gas consumption represented 98% of the total energy consumption [39]. Koroneos and Dompros [40] calculated the energy consumption in a Greek brick manufacturing process, with pet-coke being the main energy source with almost 100% of the total energy consumption. The manufacturing process of a Thai ceramic tile consumes 62% of liquefied petroleum gas (propane and butane), 24% of electricity and 14% of furnace oil [41]. Research results show that the used energy sources and share vary significantly, depending on the ceramic product, manufacturing process and location of the mill.

IV. CONCLUSIONS

The objective of this study was successfully reached, as current negative environmental impacts were identified in various stages of red ceramic production in Northeast Brazil. The nature of the environmental impacts of the red ceramic industry was confirmed as intense, punctual and limited in space – except for the emission of gaseous effluents from the kilns. The need for additional research on energy sources used in the kilns was also highlighted, in order to determine a more appropriate and rational fuel alternative.

The impacts identified in situ were the extraction of the clay from natural deposits, the extraction of firewood for the burning stage, the generation of solid byproducts, and the release of gaseous effluents into the environment.

When considering the carbon footprint (CF) of the bricks produced at the study site, the use of firewood yielded the lowest CF per kg of brick produced. Electricity (medium voltage) purchased from the electric grid and natural gas presented almost the same CF, approximately 280% higher than the business as usual scenario (firewood).

ACKNOWLEDGMENTS

This work was supported by the National Council for Scientific and Technological Development (CNPq), under projects 303199/2015-6 and 305419/2015 3.

REFERENCES

[1] W. D. Callister and D. G. RETHWISCH, *Materials science and engineering*. NY, USA: John Wiley & Sons, 2011.

[2] ANICER – Brazilian National Ceramics Industry Association. Sector data. [Online]. Available: http://www. anicer.com.br.

[3] V. M. John, V. Agopyan, C. Sjöström, "On Agenda 21 for Latin American and Caribbean Construbusiness - A Perspective from Brazil." in *CIB's Agenda 21 for Sustainable Construction for Developing Countries*, 2002.

[4] European Bank, 2012. Sub-Sectoral Environmental Guidelines - Brick Manufacture. [Online]. Available: http://www.ebrd.com/environment/e-manual/subsecs/bricks.pdf.

[5] J. B. Guinée (ed), *Life Cycle Assessment: An operational guide to the ISO Standards; LCA in Perspective; Guide; Operational Annex to Guide*. The Netherlands: Centre for Environmental Science, Leiden University, 2001.

[6] J. B. Guinée, *Handbook on life cycle assessment: operational guide to the ISO standards*. Boston, USA: Kluwer Academic Publishers, 2002.

[7] M. Carvalho, J. A. M. Silva, "Second law assessment of a Hoffmann kiln for the red ceramics industry". *Arabian Journal for Science and Engineering*, [accepted] 2017.

[8] ISO 14040, *Environmental management - Life cycle assessment - Principles and framework*. Geneva, Switzerland: International Organization for Standardization (ISO), 2006.

[9] ISO 14044, *Environmental management - Life cycle assessment - Requirements and guidelines*. Geneva, Switzerland: International Organization for Standardization (ISO), 2006.

[10] ISO. (2006) ISO standards for life cycle assessment to promote sustainable development. [Online]. Available at: https://www.iso.org/news/2006/07/Ref1019.html.

[11] M. Carvalho, L. M. Serra, M. A. Lozano, "Geographic evaluation of trigeneration systems in the tertiary sector. Effect of climatic and electricity supply conditions". *Energy*, vol. 36, n. 4, pp. 1931-1939, 2011.

[12] Solidworks. (2017) Environmental indicators. [Online]. Available: https://www.solidworks.com/sustainability/sustainable-design-guide/ch3-choice-1-environmental-indicators.htm.

[13] E. Austermann. (2014) Advantages Of A Global Strategy For Carbon Emissions Reduction. [Online]. Available: https://cleantechnica.com/2014/03/10/advantages-global-strategy-carbon-emissions-reduction/.

[14] ISO 14067. *Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification and communication*. Geneva, Switzerland: International Organization for Standardization (ISO), 2013.

[15] M. Finkbeiner, R. Tan, M. Raimbault, "Life cycle assessment (ISO 14040/44) as basis for environmental declarations and carbon footprint of products". in *ISO Technical Committee 207 Workshop*, Norway, 2011.

[16] A. Avadi, "Carbon Footprinting – CFP as an environmental management tool" in *TEMPUS Workshop*, Umwelt-Campus Birkenfeld, 2010.

[17] P. Schepelmann, et al., "Report on the SWOT analysis of concepts, methods and models potentially supporting LCA". European Commission, Brussels, 2008.

[18] B. P. Weidema, et al., "Carbon footprint". *Journal of industrial Ecology*, vol. 12, n. 1, pp. 3-6, 2008.

[19] Pré-Consultants. (2017) SimaPro website. [Online]. Available: http://www.pre-sustainability.com/.

[20] Ecoinvent. (2015) Database, version 3. [Online]. Available: http://www.ecoinvent.ch.

[21] IPCC - Intergovernmental Panel on Climate Change. (2013) Revised supplementary methods and good practice guidance arising from the Kyoto protocol. [Online]. Available: http://www.ipcc-nggip.iges.or.jp/public/kpsg/.

[22] V. Sheoran, A. S. Sheoran, P. Poonia, "Soil Reclamation of Abandoned Mine Land by Revegetation: A Review". *International Journal of Soil, Sediment and Water*, vol. 3, n. 2, article 13, 2010.

[23] EPA – U.S. Environmental Protection Agency. (1995) AP 42, Fifth Edition, Volume I, Chapter 11: Mineral Products Industry, Subchapter 25 Clay Processing. [Online]. Available: http://www.epa.gov/ttnchie1/ap42/ch11/final/c11s25.pdf.

[24] N. Nhlanhla, E. Muzenda, J. Zvimba, "Using Tyre Derived Fuel: An Analysis of the Benefits" in *International Conference on Emerging Trends in Engineering and Technology (ICETET'2013)*, Patong Beach, Phuket (Thailand), 2013.

[25] C. G. Pandya, "Energy from solid waste - the derived fuel". *The Alternative Energy e-Magazine*, December 2007. <http://www.altenergymag.com/article/2007/12/tire-derived-fuel/390/> Access 29 may 2017.

[26] A. Ayats, E. Jiménez, J. Cabré, "Energy recovery of biogas generated in landfills for manufacturing high quality ceramic products" in *Eleventh International Waste Management and Landfill Symposium*, Sardinia, Italy, 2007.

[27] P. C. A. Gondim, U. U. Gomes, E. C. Silva, W. B. N. Souza, "Viabilidade técnica de conversão de cerâmicas do Rio Grande do Norte para gás natural" in *Proceedings of the Congresso Brazileiro de Engenharia e Ciência dos Materiais*, Foz do Iguaçu, Brazil, 2006.

[28] Brazil - Ministry of Mines and Energy, *National Energy Balance 2016*. Brasília, Brazil: MME, 2016.

[29] IBAMA, Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (2017) [Online]. Available: http://www.ibama.gov.br.

[30] S. S. X. Tertuliano, "Reforestation project – CECIDA". João Pessoa, Brazil, 2002.

[31] J. Kanowski, et al., "Development of forest structure on cleared rainforest land in eastern Australia under different styles of reforestation". *Forest Ecology and Management*, vol. 183, pp. 265–280, 2003.

[32] J. Sayer, U. Chokkalingam, J. Poulsen, "The restoration of forest biodiversity and ecological values". *Forest Ecology and Management*, vol. 201, pp. 3–11, 2004.

[33] D. Lamb, P. D. Erskine, J. A. Parrotta, "Restoration of Degraded Tropical Forest Landscapes". *Science*, vol. 310, n. 5754, pp. 1628–1632, 2005.

[34] IPCC (2017) Frequently Asked Questions. Task Force on National Greenhouse Gas Inventories. [Online]. Available: http://www.ipcc-nggip.iges.or.jp/faq/faq.html.

[35] P. Quinteiro, et al., “The carbon footprint and energy consumption of a commercially produced earthenware ceramic piece”. *Journal of the European Ceramic Society*, vol. 32, n. 10, pp. 2087-2094, 2012.

[36] G. M. Nicoletti, B. Notarnicola, G. Tassielli, “Comparative Life Cycle Assessment of flooring materials: ceramic versus marble tiles”. *Journal of Cleaner Production*, vol. 10, n. 3, pp. 283-296, 2002.

[37] S. Goldoni, A. Bonoli, “A case study about LCA of ceramic sector: application of life cycle analysis results to the environment management system adopted by the enterprise”. University of Bologna, Italy, 2006.

[38] M. D. Bovea, et al., “Environmental performance of ceramic tiles: improvement proposals”. *Materials & Design*, vol. 31, n. 1, pp. 35–41, 2010.

[39] M. I. Almeida, et al., “Life cycle assessment (cradle to gate) of a Portuguese brick” in *Portugal SB10-sustainable building affordable to all*. Vilamoura, Portugal: Universidade do Minho, 2010.

[40] C. Koroneos, A. Dompros, “Environmental assessment of brick production in Greece”. *Building and Environment*, vol. 42, n. 5, pp. 2114-2123, 2007.

[41] N. Tikul, P. Srichandr, “Assessing the environmental impact of ceramic tile production in Thailand”. *Journal of the Ceramic Society of Japan*, vol. 118, n. 1382, pp. 887-894, 2010.